Nutrient excretion and odorant production in manure from cattle fed corn wet distillers grains with solubles[1,2]

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ABSTRACT: Twenty-four cross bred steers (BW 452.5 ± 15.5 kg) were used to evaluate nutrient excretion and odorous compounds in urine and feces of feedlot steers fed diets containing corn wet distillers grains with solubles (WDGS). Cattle were weighed, blocked by BW, and assigned randomly to 1 of 4 dry-rolled corn-based diets containing 0, 20, 40, or 60% WDGS (DM basis). A 96-h total fecal and urine collection was conducted. Orts, feces, and urine were collected daily. Samples were analyzed for moisture, total N, total P, water soluble P, and total S. Fresh fecal samples were collected at the end of the balance trial for analysis of VFA, phenol, *p*-cresol, indole, skatole, ammonia-N, and lactate concentration. Total P, N, and S intake increased linearly as the amount of WDGS increased in the diet ($P \leq 0.02$). Total P excretion increased linearly ($P < 0.01$), attributed to a significant linear increase in urinary P excretion as the amount of WDGS increased in the diet ($P = 0.02$). Water-soluble P excretion in feces was similar for cattle fed all 4 diets ($P \geq 0.11$). Total N excretion increased linearly as dietary WDGS inclusion increased ($P < 0.01$) and was due to a linear increase in urinary N excretion ($P < 0.01$). Total S excretion also increased as WDGS concentration increased in the diet ($P < 0.01$). Dietary treatment did not affect the concentration of odorous compounds in urine ($P \geq 0.07$). Total VFA concentration in feces decreased as WDGS increased in the diet ($P < 0.01$), but branched-chained VFA concentrations (isobutyrate and isovalerate) and phenol in feces increased when WDGS replaced corn in the diet ($P \leq 0.04$). There was no difference in the concentration of the other aromatic compounds (*p*-cresol, indole, skatole) in feces from cattle fed the 4 dietary treatments ($P \geq 0.09$). This study indicates that feedlot cattle fed increasing amounts of WDGS had increased P, N, and S intake and excretion, which may contribute to the production of odorous compounds (primarily long- and branched-chain VFA, and phenol) as well as increased ammonia and H_2S emissions from the feedlot. Increased P concentration in livestock waste will increase the amount of land necessary to utilize manure P. Because of increased urinary P excretion, producers should consider environmental implications of liquid runoff from the feedlot surface as well as solid manure when WDGS are fed to feedlot cattle.

Key words: distillers grain, feedlot cattle, nitrogen, odor, phosphorus, sulfur

J. Anim. Sci. 2009. 87:2977–2984
doi:10.2527/jas.2008-1584

INTRODUCTION

Odor emissions are an increasingly difficult and pressing problem for feedlot producers. Livestock excreta is composed of undigested organic residues, including proteins, carbohydrates, and fats. Aerobic and anaerobic digestion of organic residues by bacteria produces volatile organic compounds (**VOC**) such as ammonia, VFA, S compounds, and aromatic compounds (Mackie et al., 1998). Some VOC present in livestock manure correlate strongly to odor perception by humans (Zahn et al., 1997, 2001; Powers et al., 1999). Therefore, controlling the formation of odor-causing VOC may decrease odor in livestock facilities. Feeding practices that influence the excretion of starch or N by cattle may significantly affect the production of odor-causing VOC from cattle feedlots (Miller and Varel, 2002).

Phosphorus and S concentrations in livestock manure are also an environmental concern of cattle feedlots. Dietary P intake influences the amount of P excreted in livestock manure (Morse et al., 1992; Wu et al., 2000; Ebeling et al., 2002) and affects the amount of land necessary for manure application and the potential for

[1]Mention of trade names or commercial products is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the USDA.

[2]Technical assistance of S. Wise, T. Post, C. Felber, C. Haussler, J. Waechter, and K. Sorensen (US Meat Animal Research Center) and secretarial assistance of J. Nierman (US Meat Animal Research Center) are appreciated.

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Received October 24, 2008.
Accepted May 26, 2009.

Table 1. Ingredient and nutrient composition (DM basis) of diets containing 0, 20, 40, or 60% corn wet distillers grains with solubles (WDGS)

	Corn WDGS, % of DM			
Item	0	20	40	60
Ingredient				
Alfalfa hay, ground	10.6	10.6	10.6	10.6
Corn, dry rolled	82.7	68.2	48.2	28.2
Corn WDGS[1]	0.0	20.0	40.0	60.0
Soybean meal	5.66	—	—	—
Urea	0.40	—	—	—
Limestone	0.56	1.1	1.1	1.1
Vitamin A, D, E[2]	0.008	0.008	0.008	0.008
Mineral supplement[3]	0.007	—	—	—
Salt	0.062	—	—	—
Monensin[4]	0.030	0.030	0.030	0.030
Thiamine premix,[5] 88 g/kg	0.023	0.023	0.023	0.023
Analyzed composition				
DM, %	86.1	61.8	49.5	42.6
CP, %	12.6	14.8	19.6	25.0
Fat, %	1.0	6.6	7.4	10.9
P, %	0.34	0.40	0.49	0.57
S, %	0.33	0.39	0.50	0.58
Calculated composition[6]				
ME, Mcal/kg	3.11	3.06	3.05	3.02
CP/ME	43.22	47.61	61.00	74.43
UIP, %	48.07	50.46	49.80	49.00
NE_m, Mcal/kg	2.11	2.09	2.07	2.05
NE_g, Mcal/kg	1.44	1.42	1.41	1.40
ADF, %	6.14	9.75	12.50	15.23
NDF, %	12.08	19.34	23.94	28.55

[1]Corn WDGS obtained from Abengoa Bioenergy Corp., York, NE. Nutrient analysis was 31.3% DM, 31.6% CP, 13.7% oil, 0.83% P, and 0.73% S (DM basis).

[2]The supplement provided 8,800,000 IU of vitamin A; 880,000 IU of vitamin D; and 880 mg/kg of vitamin E per kg.

[3]Trace mineral premix contained 13% Ca, 12% Zn, 8% Mn, 10% Fe, 1.5% Cu, 0.2% I, and 0.1% Co.

[4]Rumensin 80 (Elanco Animal Health, Indianapolis, IN).

[5]Provides 200 mg per animal daily.

[6]Used tabular values (NRC, 2000). UIP = undegradable intake protein.

P runoff. Excreted S can contribute to H_2S emissions from livestock manure (Shurson et al., 1998).

Corn wet distillers grains with solubles (**WDGS**) are a common feed ingredient in cattle feedlot diets with increased N, P, and S contents relative to cattle nutrient needs (NRC, 2000). Optimal ADG and feed efficiency is achieved when WDGS are included at 30% of the diet DM in dry-rolled corn-based feedlot diets (Erickson et al., 2007). Use of WDGS at this dietary concentration may have environmental implications including odor production and concentration of nutrients such as N, P, and S in cattle manure. The objective of this study was to test the hypothesis that cattle fed diets containing WDGS would excrete more N, P, and S, and less starch than cattle fed dry-rolled corn, resulting in increased concentration of odorous compounds in cattle manure.

MATERIALS AND METHODS

All animal procedures were reviewed and approved by the US Meat Animal Research Center Animal Care and Use Committee.

Animals and Experimental Procedures

Twenty-four cross bred steers from the US Meat Animal Research Center (Clay Center, NE) were used for the study. Steers were weighed, blocked by BW, and assigned randomly within block to 1 of 4 dry-rolled corn-based diets containing 0, 20, 40, or 60% WDGS on a DM basis (Table 1). There were 8 steers per block with each dietary treatment replicated twice within block. The steers were allowed ad libitum access to feed and water at all times during the acclimation and collection periods.

Steers were provided a 6-wk acclimation period to diets, facilities, and close human contact before starting the nutrient balance study. The cattle were 292 to 337 d of age and had an initial BW of 378 ± 7.8 kg when the adaptation period began. During the adaptation period, cattle were housed in individual stalls (87 × 214 cm) from 0800 to 1500 h each day. The stalls were located in an enclosed barn, and each stall had automatic, individual water cups and an individual feeding box. When cattle were not in the stalls, they were housed in open-lot dirt pens. There were 4 open pens,

and cattle were grouped in pens according to dietary treatment.

The experiment consisted of 3 collection periods with 8 steers (2/treatment) per collection period. One block of animals was used for each collection period. Each collection period consisted of a 96-h nutrient (N, P, and S) balance trial with total collection of feces and urine. Cattle were weighed at the beginning and end of the 96-h collection period and housed in individual stalls. Fresh feed was provided at 1000 h each day. The amount of feed provided and orts were weighed daily to determine apparent DMI. Urine was aspirated from a urine collection harness into polypropylene jugs that contained 100 mL of 3.6 *M* HCl. Feces were collected into fecal bags. Fecal bags and urine collection jugs were changed and samples collected between 0800 and 1000 h each day. Feces, urine, and orts were collected daily, weighed, and an aliquot of each (5% of daily output) was pooled within steer and frozen until analyzed. A subsample of feed from each dietary treatment was also collected daily, pooled by treatment, and frozen until analyzed.

Feces, urine, orts, and feed were analyzed for total P (Fiske and Subbarow, 1925) and N (AOAC, 1976). Sulfur was analyzed using an inductively coupled plasma procedure at a commercial laboratory (Servi-Tech, Hastings, NE). Water-soluble P was also determined in fecal samples using a commercially available assay kit (Diagnostic Chemical Limited, Charlottetown, Prince Edward Island, Canada) using the procedure of Daly and Ertingshausen (1972) but was not measured in urine samples. Concentration of N, P, and S in feces, urine, and feed were used to determine apparent intake and excretion (urine + feces) of N, P, and S by animals. Apparent N, P, and S retention was determined by subtracting excretion from intake.

The trial was conducted during the warm summer months, and fermentation of feces likely occurred in the fecal bags, potentially altering pH and VOC concentration in the feces. Therefore, fresh fecal samples were collected at the end of the 96-h balance trial, immediately frozen to prevent fermentation, and subsequently analyzed for pH, ammonia, L-lactate, acetate, propionate, butyrate, isobutyrate, isovalerate, valerate, isocaproate, caproate, heptanoate, total VFA, phenol, *p*-cresol, indole, and skatole. Fecal pH was obtained by using a combination electrode and PHM 83 pH meter (Radiometer America, Cleveland, OH) in fecal samples diluted 1:1 with deionized water. Samples were diluted before sampling to form a slurry. Fecal and urinary ammonia was determined using a modification of the Sigma urea N kit (procedure No. 640, Sigma-Aldrich Chemicals, St. Louis, MO). Standards and samples were diluted 10-fold with deionized water and 5 μL was transferred to a well in a 96-well microtiter plate. This was followed by additions of 50 μL of phenol nitroprusside, 50 μL of alkaline hypochlorite, and 250 μL of distilled water. Color was allowed to develop for 20 to 30 min at room temperature. Absorbance at 620 nm was measured using a Bio-Tek Ceres UV900C microplate reader (Bio-Tek Instruments, Winooski, VT). The concentration of each 96-well plate was determined from a standard curve run with the plate, and the CV of each duplicate sample in the plate was less than 3%. A YSI Model 2700 autoanalyzer (Yellow Springs Instrument, Yellow Springs, OH) was used to analyze L-lactate, and a Hewlett-Packard 6890 gas chromatograph (Agilent Technologies, Palo Alto, CA) equipped with flame-ionization and mass-selective detectors was used to determine concentrations of all other odorous compounds as described previously by Miller and Varel (2001).

Data were analyzed as a randomized complete block design using GLM procedures (SAS Inst. Inc., Cary, NC). The model included the main effects of diet and block. Orthogonal contrasts were used to analyze linear and quadratic effects of adding WDGS to the diets. An α value of 0.05 was used to assess significance of contrasts. Animal was the experimental unit.

RESULTS

Average BW of cattle at the time of collection was 452.5 ± 15.5 kg and did not differ among cattle fed the 4 dietary treatments ($P \geq 0.60$). There was a linear decrease in DMI as the concentration of WDGS increased in the diet ($P < 0.01$; Table 2). Cattle consumed 8,357, 6,980, 6,898, and 1,660 g of DM/d when fed the 0, 20, 40, and 60% WDGS diets, respectively. Fecal DM excretion was similar among cattle fed the 4 dietary treatments ($P \geq 0.08$), but fecal DM percentage decreased linearly ($P < 0.01$) as the concentration of WDGS increased in the diet. Apparent DM digestibility was 73.3, 71.4, 70.9, and 71.9% for cattle fed the 0, 20, 40, and 60% WDGS diets, respectively ($P \geq 0.31$). Daily urinary output was similar between cattle fed all 4 dietary treatments ($P \geq 0.12$; Table 2), but quite variable.

Total P intake ($P = 0.02$) and total P excretion ($P < 0.01$) increased linearly as the amount of WDGS increased in the diet (Table 2). Phosphorus excreted in the feces was similar for cattle fed all 4 dietary treatments ($P \geq 0.13$), whereas urinary P excretion increased (linear, $P = 0.02$) when WDGS replaced corn in the diet. Urinary P concentrations were similar for cattle fed the 4 dietary treatments (0.12, 0.15, 0.12, and 0.13%, respectively, for the cattle fed the 0, 20, 40, and 60% WDGS diets; $P \geq 0.45$). There was a positive linear relationship between total P excretion and fecal P excretion ($P < 0.01$; $R^2 = 0.16$) but an even stronger linear relationship between total P excretion and urinary P excretion ($P < 0.001$; $R^2 = 0.67$): urinary P excretion (g/d) = $-6.25 + [0.770 \times$ total P excretion (g/d)]. Urinary P excretion accounted for 41.3, 41.2, 52.1, and 45.5% of total P excretion for the 0, 20, 40, and 60% WDGS diets, respectively ($P \geq 0.48$). There was no difference in apparent P retention between cattle fed the 4 dietary treatments ($P \geq 0.12$). Fecal water soluble P accounted for 9.5 to 12.7% of the P excreted

Table 2. Phosphorus, nitrogen, and sulfur balance for feedlot steers[1] fed 0, 20, 40, or 60% corn wet distillers grains with solubles in dry-rolled corn-based finishing diets

	Corn wet distillers grains with solubles, % of DM					*P*-value	
Item, g/d	0	20	40	60	SEM	Linear	Quadratic
DMI	8,357	6,980	6,989	6,160	194.5	<0.01	0.51
Urine output, as-is basis	6,102	6,538	11,541	8,914	693.8	0.12	0.30
Fecal DM output	2,215	2,025	2,037	1,745	72.2	0.08	0.84
Fecal DM, %	26.5	23.6	23.1	22.4	0.3	<0.01	0.23
Total tract DM digestibility, %	73.3	71.4	70.9	71.9	0.6	0.50	0.31
Phosphorus							
Total P intake	27.8	27.5	34.1	35.0	0.8	0.02	0.68
Total P excreted	14.6	19.4	20.5	24.8	0.7	<0.01	0.88
Feces	8.7	11.6	11.3	12.1	0.5	0.13	0.24
Urine	5.9	7.8	9.2	12.7	0.7	0.02	0.36
Apparent total P retained[2]	13.2	8.1	13.6	10.2	0.7	0.12	0.49
Fecal water soluble P excreted	0.9	1.4	1.3	1.6	0.1	0.11	0.45
Nitrogen							
Total N intake	169.6	169.3	222.8	243.6	5.2	<0.01	0.79
Total N excreted	110.2	120.9	150.2	174.6	5.7	<0.01	0.91
Feces	57.8	57.8	61.6	54.0	1.5	0.57	0.65
Urine	52.4	63.1	88.6	120.6	4.5	<0.01	0.21
Apparent total N retained[3]	59.4	48.4	72.6	69.0	3.4	0.25	0.52
Sulfur							
Total S intake	11.7	16.9	25.0	28.7	0.6	<0.01	0.95
Total S excreted	8.3	14.1	22.2	18.7	0.8	<0.01	0.09
Feces	4.8	5.3	6.5	6.0	0.2	0.02	0.42
Urine	3.5	8.8	15.7	12.7	0.7	<0.01	0.09
Apparent total S retained[4]	3.4	2.8	2.8	10.0	0.8	0.03	0.05

[1]n = 24 steers (452.5 ± 15.5 kg), 6 steers per dietary treatment.
[2]Apparent total P retained (g/d) = total P intake (g/d) − total P excreted feces (g/d) − total P excreted urine (g/d).
[3]Apparent total N retained (g/d) = total N intake (g/d) − total N excreted feces (g/d) − total N excreted urine (g/d).
[4]Apparent total S retained (g/d) = total S intake (g/d) − total S excreted feces (g/d) − total S excreted urine (g/d).

in the feces and was similar across all dietary treatments ($P \geq 0.11$).

Nitrogen intake increased linearly as concentration of WDGS increased in the diet ($P < 0.01$; Table 2). Fecal N excretion was similar among steers fed the 4 dietary treatments ($P \geq 0.57$), whereas urinary N excretion increased linearly ($P < 0.01$) as the concentration of WDGS increased in the diet. This resulted in a linear increase in total N excretion as WDGS replaced corn in the diet ($P < 0.01$). Urinary N concentrations were 0.83, 1.06, 0.91, and 1.44% for the cattle fed the 0, 20, 40, and 60% WDGS diets, respectively (linear, $P < 0.01$). The proportion of total N excreted as urinary N increased linearly as the level of WDGS increased in the diet ($P < 0.01$). Urinary N accounted for 46.1, 51.1, 57.5, and 68.0% of total N excretion when the 0, 20, 40, and 60% WDGS diets were fed, respectively. Apparent N retention was similar for cattle fed the 4 dietary treatments ($P \geq 0.25$).

There was a linear increase in S intake as the concentration of WDGS increased in the diet ($P < 0.01$; Table 2). Fecal S excretion also increased as the amount of WDGS increased in the diet (linear, $P = 0.02$). Urinary S concentration was 0.06, 0.15, 0.15, and 0.15% for the cattle fed diets containing 0, 20, 40, and 60% WDGS, respectively (quadratic, $P = 0.02$), which resulted in a linear increase ($P < 0.01$) in urinary S excretion as WDGS replaced corn in the diet.

Volatile fatty acids were in very low concentrations (total VFA <2.5 μmol/mL) or not detected in urine and did not differ between dietary treatments (data not shown). Concentrations of aromatic compounds and ammonia-N in urine were similar for cattle fed the 4 dietary treatments ($P \geq 0.07$; Table 3).

Total VFA concentration in feces decreased as WDGS replaced corn in the diet ($P < 0.01$), which was largely due to linear decreases in butyrate ($P < 0.01$) and propionate ($P < 0.01$) as WDGS concentration increased in the diet. Fecal isocaproate concentration also decreased as the amount of WDGS increased in the diet ($P = 0.01$). Isobutyrate ($P < 0.01$), isovalerate ($P < 0.01$), caproate ($P < 0.01$), and heptanoate ($P < 0.01$) concentrations in feces increased and fecal valerate tended to increase ($P = 0.06$) as the dietary concentration of WDGS increased.

There was no difference in the concentration of *p*-cresol, indole, or skatole in feces from cattle fed the 4 dietary treatments. Phenol was not detected in feces of cattle fed the 0 or 20% WDGS diets but was present in feces from cattle fed diets containing 40 and 60% WDGS (linear, $P = 0.04$). There was a linear increase in fecal ammonia-N concentration as level of WDGS increased in the diet. Concentration of L-lactate concentration was greater in fresh fecal samples collected from steers fed the control diet compared with fecal samples from steers fed the 3 WDGS diets (linear, *P*

Table 3. Concentration of DM, L-lactate, and pH in feces and odorants in feces and urine of steers[1] fed 0, 20, 40, or 60% corn wet distillers grains with solubles in dry-rolled corn-based finishing diets

	Corn wet distillers grains with solubles, % of DM					*P*-value	
Item	0	20	40	60	SEM	Linear	Quadratic
Urine							
Aromatic compounds, μmol/mL							
Phenol	0.05	0.05	0.05	0.08	0.01	0.21	0.35
Cresol	1.90	1.33	0.56	1.14	0.13	0.10	0.07
Indole	4.69	2.45	1.83	2.07	0.60	0.17	0.47
Skatole	0.09	0.02	0.01	0.03	0.01	0.10	0.07
Ammonia-N, g/mL	1.14	0.45	0.63	1.04	0.15	0.98	0.19
Feces							
DM, %	26.0	23.6	23.2	22.8	0.34	<0.01	0.23
VFA, μmol/g of DM							
Acetate	220.5	240.2	235.8	224.8	5.8	0.09	0.23
Butyrate	113.1	115.5	52.3	47.8	2.4	<0.01	0.76
Propionate	206.8	208.1	140.2	112.9	4.5	<0.01	0.59
Valerate	6.3	9.3	9.0	9.6	0.5	0.06	0.35
Caproate	0.66	0.77	0.89	1.36	0.01	<0.01	0.07
Heptanoate	0.00	0.00	0.00	0.06	0.01	0.01	0.07
Isobutyrate	1.79	2.75	3.23	4.99	0.17	<0.01	0.28
Isovalerate	1.81	2.70	3.05	4.85	0.18	<0.01	0.25
Isocaproate	0.76	0.76	0.25	0.27	0.07	0.01	0.98
Total VFA	551.7	580.1	444.8	406.7	10.7	<0.01	0.55
Aromatic compounds, μmol/g of DM							
Phenol	0.00	0.00	0.08	0.06	0.01	0.04	0.84
Cresol	0.11	0.24	0.75	0.30	0.10	0.33	0.41
Indole	2.32	3.73	4.62	3.98	0.32	0.09	0.26
Skatole	1.32	3.24	1.89	3.49	0.28	0.11	0.78
Ammonia-N, mg/g of DM	10.2	13.6	21.0	27.0	1.15	<0.01	0.32
L-Lactate, μmol/g of DM	16.8	8.0	3.0	3.9	1.14	<0.01	0.79
pH	5.8	6.2	6.3	6.5	0.10	0.04	0.11

[1]n = 24 steers (452.5 ± 15.5 kg), 6 steers per dietary treatment.

< 0.01). Fecal pH increased linearly as level of WDGS increased in the diet, ranging from 5.8 for steers fed the control diet to 6.5 in feces from cattle fed the 60% WDGS ($P = 0.04$).

DISCUSSION

The WDGS used in this study contained 31.6% CP, 0.83% P, and 0.73% S, which is similar to previously reported nutrient values for WDGS (NRC, 1996; Holt and Pritchard, 2004; Erickson et al., 2007). This is an approximate 3-fold increase in CP, P, and S concentration compared with corn (NRC, 1998). When WDGS was added at 20, 40, or 60% of the diet DM as a replacement for corn, subsequent increases in dietary N, P, and S concentrations resulted. Consequently, N, P, and S intake increased linearly as the amount of WDGS increased in the diet, even with a linear decrease in DMI. Previous research has clearly demonstrated that cattle consuming dietary N (Cole et al., 2005; Archibeque et al., 2007), P (Benson et al., 2006; Luebbe et al., 2008), and S (Fron et al., 1990) in excess of nutrient needs will excrete the extra nutrients in urine and feces. The nutrients in urine and feces can then be volatilized into the atmosphere, runoff or leach into nearby water, or be metabolized by fecal microbes to produce odorous compounds that negatively affect air quality. Thus, the importance of understanding the effects of feeding WDGS to feedlot cattle on nutrient excretion and concentrations of odorous compounds in cattle manure.

Dry matter intake is a key factor that determines how much of a nutrient will be digested, absorbed, utilized, and excreted by an animal (Colucci et al., 1982). Dry matter intake is influenced by environmental factors such as temperature and photoperiod, as well as physical and chemical composition of the feed. Cattle will adjust voluntary DMI to physiological demand for energy (NRC, 2000). It is likely that the greater fat content of WDGS relative to corn substantially increased dietary energy intake and decreased DMI, which is consistent with previous research in which high-fat diets were fed to finishing cattle (Clary et al., 1993; Zinn and Shen, 1996; Andrae et al., 2000).

Sulfur in distillers coproducts comes from 2 primary sources: sulfuric acid during ethanol production and S-containing AA. Increased S concentration in the rumen can stimulate ruminal microbes to produce excess H_2S, which can potentially cause the neurological disease polioencephalomalacia. The maximum tolerable S concentration for cattle is 0.30% of the diet DM (NRC, 2005). However, dietary S concentrations provided in excess of requirements but less than those needed to cause clinical signs of toxicity can reduce DMI and growth rate (Thompson et al., 1972; Rumsey, 1978; NRC, 1996).

Cattle fed diets containing WDGS had substantially greater S intake than cattle fed the control diet. Although no signs of S toxicity were observed in this study, increased S intake may have contributed to the linear decrease in DMI as level of WDGS increased in the diet.

Fecal DM excretion was similar across all dietary treatments, indicating that finishing cattle fed diets containing WDGS will produce a similar quantity of manure as cattle fed a dry-rolled corn diet. However, the nutrient content (N, P, and S) of manure from cattle fed WDGS was substantially different than manure from cattle fed dry-rolled corn, which may affect nutrient management plans for feedlots using WDGS in finishing diets.

Dietary P is often fed in excess of daily requirements. The dietary P requirement for a feedlot steer is 0.30% of the diet DM (NRC, 1996). A more recent study by Erickson et al. (2002) suggests the dietary P requirement for feedlot steers may be as low as 0.16% of diet DM. In this study, dietary P was fed well above these recommended requirements. As a result, total P excretion increased as the level of WDGS increased in the diet. This is consistent with previous studies that reported cattle fed diets containing distillers coproducts have greater total P excretion than cattle fed corn-based diets (Benson et al., 2006; Luebbe et al., 2008).

It is commonly accepted that the major route of P excretion for ruminant animals is feces, with only small amounts of P excreted in the urine (Horst, 1984; Betteridge et al., 1986; Morse et al., 1992). Although there was a numeric increase in fecal P as concentration of WDGS increased in the diet, this difference was not significant. Instead, the linear increase in total P excretion in this study can be attributed to a significant linear increase in urinary P excretion as the amount of WDGS increased in the diet. These results are consistent with Meyer et al. (2006), who also reported a significant increase in urinary P excretion when 10 and 20% WDGS were added to dry-rolled corn diets with urinary P comprising 32.4, 32.1, and 34.8% of the total P excreted for the dry-rolled corn, 10% WDGS, and 20% WDGS diets, respectively.

Urinary losses of P are generally small but may increase once serum P concentration reaches a renal threshold (Challa and Braithwaite, 1988a,b; Ternouth et al., 1996). In ruminant animals, P homeostasis in the blood primarily involves salivary-P secretions and fecal excretions (Horst, 1984). Cattle fed high-concentrate diets ruminate less than those fed high-forage diets (Bailey, 1961; Bailey and Balch, 1961) and therefore produce less saliva, which may reduce the amount of P recycled into the gastrointestinal tract. As a result, serum P concentrations increase. Though salivary P was not measured directly in this study, it does provide a possible explanation for the increased urinary P excretion when WDGS was fed to finishing cattle. When high-concentrate diets containing WDGS were fed, there was reduced salivary-P recycling coupled with increased dietary P intake. The renal P threshold was likely reached, and urinary P excretion increased. Urinary P excretion in this study contributed 42.1 to 52.1% of the total P excretion when diets containing WDGS were fed and could affect the P concentration in the liquid runoff from the feedlot surface.

Increasing dietary P concentration, and the subsequent increase in P excretion, increases the amount of land necessary to utilize manure P. Satter et al. (2002) demonstrated that increasing dietary P concentration in diets of lactating dairy cows from 0.35 to 0.55% increased the land area needed to recycle manure P by 83%. Similarly, Bremer et al. (2008) compared land area necessary to manage P in manure from 10,000 feedlot cattle fed diets containing 0 to 40% distillers grains plus solubles. Dietary P concentrations ranged from 0.29 to 0.49% for the 0 and 40% distillers grains plus solubles diets, respectively. Nearly twice as much land was needed to properly manage P in feedlot manure when cattle were fed diets containing 40% distillers grains plus solubles compared with 0% distillers grains plus solubles (4,480 vs. 2,339 ha, respectively). Producers who use high levels of WDGS in feedlot diets need to secure additional land area for manure application to properly manage greater P concentration in manure.

Water soluble P tended to increase with inclusion of WDGS. This could potentially increase P runoff when manure is applied to cropland. Ebeling et al. (2002) reported that P concentration in dairy diets influenced the forms and amounts of P in manure. Greater P concentration in the diet resulted in greater dissolved reactive P in manure. More research is needed to determine conclusively if the use of WDGS in cattle diets increases the concentration of water soluble P in manure because this may affect manure application rates and land area necessary to manage manure P concentration.

The average CP content of WDGS used in the study was 31.6%, whereas corn has an average CP content of only 9.8% (NRC, 2000). Consequently, total N intake increased linearly when WDGS replaced corn in the diet. The proportion of total N excreted as urinary N increased as the level of WDGS increased in the diet, indicating that the excess N was predominantly excreted in the urine. Urinary N contains primarily urea, whereas fecal N contains mainly undigested feed protein and metabolic fecal N (de Boer et al., 2002). When urinary urea is exposed to the enzyme urease, which is present in feces and soil microbes, urea is rapidly converted to ammonia and volatilized into the air. Therefore, an increase in N intake and a subsequent increase in urea N excretion can result in increased ammonia emissions from the feedlot surface. Cole et al. (2005) reported that ammonia losses were highly correlated to urinary N excretion and that in vitro ammonia emissions increased 60 to 200% when CP concentration of the diet increased from 11.5 to 13%. In a related study, daily ammonia emissions from a simulated feedlot surface decreased by 44% when CP in beef cattle diets was decreased from 13 to 11.5% (Todd et al., 2006).

Archibeque et al. (2007) also found in vitro ammonia emissions increased as CP concentrations in the diet increased from 9.1 to 13.9%.

Diets containing WDGS have a greater S concentration than a dry-rolled corn diet due to greater concentration of S-containing AA in distillers grains compared with corn (NRC, 1998), which can contribute to sulfide emissions (Mackie et al., 1998). Dietary S level has been shown to be a significant contributor to odor and H_2S concentrations in confinement swine nursery facilities (Shurson et al., 1998). Pigs fed a high S diet excreted significantly more S than pigs fed a low S diet, which resulted in greater H_2S emissions from manure of pigs fed the high S diet. Benson et al. (2005) reported H_2S emissions from the feedlot surface were greater when finishing cattle were fed diets containing 35% dried distillers grains with solubles (2.22 ppb) compared with cattle fed 0, 15, and 25% dried distillers grains plus solubles (0.67, 0.56, and 0.81 μg/kg, respectively). Although H_2S production was not measured in our study, fecal and urinary S excretions were greater for cattle fed the WDGS diets. This could potentially contribute to increased H_2S emissions from feedlot pens where WDGS is fed.

Nutrient content of the feces affected the concentration of odorous compounds in the feces. Starch is the preferred substrate for microbial fermentation yielding products such as L-lactate, acetate, propionate, and butyrate in feces (Miller and Varel, 2002). Whereas these VFA comprise a large portion of the total VFA in cattle feces, they have less odor potential than long-chained VFA (C4 to C9) and branched-chain VFA (Mackie et al., 1998; Zhu, 2000). The linear increase in fecal pH is an indicator of the decreased production of L-lactate and short-chained VFA in manure of cattle fed increasing amounts of WDGS.

In the absence of starch, fecal microbes use protein as a substrate (Miller and Varel, 2002). Decarboxylation of AA in fresh manure produce branched-chain fatty acids, sulfur compounds, amines, phenols, and indoles (Spoelstra, 1980), which have a very low odor threshold (Zhu et al., 1999; Zahn et al., 2001), meaning these compounds can be detected by the human nose even at very small concentrations in the air. These processes are induced at pH 5 to 6 (Rappert and Muller, 2005), which is similar to the pH values in fresh feces from cattle fed in the current study. The relative concentrations of most all odorous compounds measured in this study are similar to Archibeque et al. (2007) in which feedlot cattle were fed diets containing 9 to 15% CP. However, it was noted by Archibeque et al. (2007) and should be emphasized in this study that there is a great deal of difficulty associated with relating concentrations of odorous compounds in livestock waste to human perception of odor. The challenge is determining an odor detection threshold of humans for the various odorous compounds. Detection of odorous compounds in feces with GC-MS does not necessarily mean release into the atmosphere. Factors such as temperature, pH, and moisture affect whether or not an odorous compound will be dissipated from livestock waste (Zahn et al., 2001). And once in the atmosphere, mixtures of gases may smell differently than unmixed compounds (Mackie et al., 1998). However, numerous studies have demonstrated that branched-chain VFA, *p*-cresol, indole, skatole, hydrogen sulfide, and ammonia seem to be important odorous compounds either by virtue of their relatively large concentrations or their low detection thresholds (O'Neill and Phillips, 1992; Zahn et al., 1997; Zhu, 2000; Rappert and Muller, 2005) and, therefore, can serve as an indicators of relative differences in odor potential when various diets are fed to feedlot cattle.

In conclusion, feedlot cattle fed increasing amounts of WDGS had increased P, N, and S intake and excretion. Increased P concentration in livestock waste will increase the amount of land necessary to utilize manure P. Because of increased urinary P excretion, producers should consider environmental implications of liquid runoff from the feedlot surface as well as solid manure when WDGS are fed to feedlot cattle. The increase in total N and S excretion contributes to the production of odorous compounds (primarily long- and branched-chain VFA, and phenol) and may increase ammonia and H_2S emissions from the feedlot. Use of WDGS in beef feedlot diets does not appear to increase the highly odorous compounds *p*-cresol, indole, or skatole.

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